STATE OF WASHINGTON
DEPARTMENT OF NATURAL RESOURCES
BRIAN J. BOYLE, Commissioner of Public Lands
ART STEARNS, Department Supervisor

DIVISION OF GEOLOGY AND EARTH RESOURCES
Raymond Lasmanis, State Geologist

THE CHUMSTICK AND WENATCHEE FORMATIONS: FLUVIAL AND LACUSTRINE ROCKS OF EOCENE AND OLIGOCENE AGE IN THE CHIWAUKUM GRABEN, WASHINGTON

by

Randall L. Gresens,[1] Charles W. Naeser,[2]
and John T. Whetten[3]

[1]Department of Geological Sciences
University of Washington
Seattle, Washington 98195

[2]U.S. Geological Survey
Denver, Colorado 80225

[3]Department of Geological Sciences
University of Washington
Seattle, Washington 98195
and
U.S. Geological Survey
Seattle, Washington 98105

Washington Department of Natural Resources
Division of Geology and Earth Resources
Olympia, Washington 98504

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Abstract: The Chiwaukum graben in central Washington contains two unconformity-bounded fluvial and lacrustrine units, here named the Chumstick and Wenatchee Formations, dated at 45 m.y. (middle to late Eocene) and 34 m.y. (early Oligocene) by the fission-track method on zircons from tuffs. Previously, both formations were thought to be part of the Swauk Formation, which is older.

The Chumstick Formation rests on weathered crystalline basement and is thousands of meters thick. Fanglomerate occurs at the base and along the margins. Most of the formation consists of feldspathic sandstone and pebbly sandstone of fluvial origin; but within the upper part is a lacustrine unit, here designated the Nahahum Canyon Member. Tuff is common in the lower part of the formation. Both of the bounding faults, the Leavenworth and the Entiat, were active during deposition of the Chumstick Formation, but relief was greatest on the northeast side.

The Wenatchee Formation is restricted to the vicinity of Wenatchee, Washington, and is $\geq$300 m thick. It unconformably overlies the Chumstick Formation within the graben but overlaps the northeast side of the graben, where it lies directly on weathered metamorphic basement. The Wenatchee Formation, like the Chumstick, was deposited primarily in fluvial and lacustrine environments; unlike the Chumstick, much of the sediment is mature quartz sandstone. Relief in the source area probably was very subdued during its deposition.

INTRODUCTION AND HISTORICAL BACKGROUND

The Chiwaukum graben in the central Cascade Range of Washington (Fig. 1) contains two Tertiary fluvial and lacustrine formations formerly considered to be part of the Swauk Formation, a unit of nonmarine sandstone, conglomerate, and shale. The Swauk was named by Russell (1900) for exposures along Swauk Creek. Its type locality is west of the graben. It is overlain unconformably by Teanaway Basalt, which, in turn, is overlain conformably by the Roslyn Formation. Rocks within the Chiwaukum graben (Willis, 1953) were called Swauk largely on the basis of lithologic similarity and evidence from fossil leaves (e.g., Chappell, 1936; Page, 1939; Willis, 1953), even though the Teanaway Basalt and Roslyn Formation were not known to occur there. In this paper, we present evidence that the rocks in the graben constitute two formations that are younger than the Swauk Formation.

Russell (1900), who mapped in the area of the western border of the Chiwaukum graben, suggested that there were two sedimentary units within the Swauk, which he called Wenache sandstone phase and Camas sandstone phase. In deference to Smith (1904), who considered differences between the sandstones to reflect facies differences in a large lake, Russell did not formally propose these names. Alexander (1956), in an unpublished M.S. thesis, suggested that the Swauk be retained and that the younger formation should be called Camas. In essence, we agree with Alexander, but since the name Camas is preempted, we use the name Chumstick Formation for the Camas sandstone of Russell (1900) and Alexander (1956). We use the name Wenatchee Formation for a third unit that is younger than the Swauk and Chumstick Formations (Fig. 2).

R.W. Tabor and V.A. Frizzell, Jr., currently working on the Swauk Formation in the type area and elsewhere, report a fission-track age of 49±5 m.y. on zircon from a tuff which they believe to be in the upper part of the Swauk (Tabor and Frizzell, 1977, p. 89). Additional details concerning previous work on the Swauk Formation are given in Gresens et al. (1977) and Tabor and Frizzell (1977).

CHUMSTICK FORMATION (JTW)

Name and General Character

The Chumstick Formation is named for Chumstick Creek, north of Leavenworth, Washington (Fig. 1). The formation is a thick deposit of interbedded sandstone, conglomerate, shale, and very minor tuff; sedimentary structures and plant remains indicate deposition in environments ranging from alluvial fan and fluvial to lacustrine. Fanglomerate occurs locally at the base of the formation and along its margins. The age of the formation is late middle to late Eocene on the basis of fission-track dating of zircons from tuffs.

Sandstone is the most common lithology. Thick whitish to buff-gray, crossbedded to massive beds typically grade from pebbly sandstone at the base to medium or fine-grained sandstone at the top. Conglomerate and shale are present locally. Most sandstones are feldspathic; clast compositions and paleocurrent determinations suggest that sediment was derived from nearby sources, mainly from the area of the Entiat Mountains.

Within the fine-grained upper part of the Chumstick Formation is a lacustrine unit designated the Nahahum Canyon Member (Fig. 2) after Nahahum Canyon, northeast of Cashmere (Fig. 3). The Nahahum Canyon Member grades into the Chumstick Formation near the margins of the graben and near what

is assumed to have been a bedrock ridge within the graben. On the northeast side of the graben, where the member is best preserved and exposed, normal faulting along the Entiat fault controlled the location of alluvial and lacustrine depositional environments.

Type Section

We designate the section along Eagle Creek (Fig. 1) as the type section of the Chumstick Formation, including the Nahahum Canyon Member, beginning at the confluence of Eagle and Chumstick Creeks (Sec. 31, T25N, R18E), approximately on the axis of the Peshastin syncline (Willis, 1953; Fig. 3), and extending northeast through both limbs and the core of the Eagle Creek anticline to the Entiat fault (Sec. 20, T25N, R19E). Metamorphic rocks in the core of the anticline (Sec. 23, T25N, R18E) are excluded from the type section.

The type section affords the most accessible overview of the entire unit, but not all lithologies are represented, and the section is incomplete because of the fault that separates the Nahahum Canyon Member from the rest of the Chumstick Formation (Whetten and Laravie, 1976).

In the following section, the major lithologies are described and reference sections given for lithologies that are not easily seen at the type section.

Lithologies and Depositional Environments

Redbed fanglomerate--The Chumstick Formation was deposited on Swakane Biotite Gneiss. The basal deposit (map unit "Tf", Whetten and Laravie, 1976; Figs. 3, 4) is a diamictite composed of angular to subrounded clasts of gneissic detritus to 50 cm in diameter and smaller clasts of vein quartz in a

reddish sandy matrix. Although thin lenses of sandstone occur locally, the fanglomerate is generally without bedding or other structures.

The rocks weather readily and are poorly exposed. A telltale reddish soil commonly develops where the unit is present, however, and slightly rounded clasts distinguish colluvium derived from it from that of Swakane Biotite Gneiss.

The fanglomerate, exposed only near the core of the Eagle Creek anticline, ranges in thickness from 0 to 200 m. Rocks of this lithology are not exposed at the type section, but a suitable reference section is located at the head of Williams Canyon on the Blag Mountain road (SW¼ Sec. 1, T24N, R18E).

The redbed fanglomerate is interpreted to be the remains of alluvial fans that mantled knobs and ridges of gneiss on the floor of the graben. The red color appears to be produced by alteration of ferromagnesian minerals (mostly biotite) in the gneiss. Although red is the typical color, some rocks are of other colors, including brown and gray.

Fanglomerate on the margins of the graben--Discontinuous lenses of conglomerate and diamictite (hereinafter referred to as fanglomerate) occur in the Chumstick Formation on the west margin of the graben along the Leavenworth fault (Cashman, 1974; Cashman and Whetten, 1976; Tabor and Frizzell, 1977; Fig. 4). These rocks intertongue with fluvial deposits of the Chumstick Formation. Similar rocks occur along the Entiat fault (map unit "Tc"; Whetten and Laravie, 1976; Whetten and Waitt, 1978) and interfinger with the Nahahum Canyon Member.

On the west side of the graben, the unit is predominantly serpentinite fanglomerate derived from the Ingalls Peridotite of Ellis (1959), diorite fanglomerate from the Mount Stuart Granodiorite, and schist fanglomerate

from the Chiwaukum Schist of Page (1939, 1940). Most fanglomerate is essentially monolithologic; locally it is a mixture of two or more rock types. The depositional environment was one of coalescing alluvial fans along the graben margin fed by streams and debris flows from one or more rapidly rising and eroding fault scarps. Maximum thickness of the fanglomerate is about 50 m, and clasts range to 3 m in diameter.

Some of the best exposures of fanglomerate are seen near Ingalls Creek Lodge on U.S. Highway 97, 12 km south of the junction with U.S. Highway 2 (SE¼ Sec. 13, T23N, R17E). On the west side of Peshastin Creek, a serpentinite fanglomerate occurs as a conspicuous reddish-brown bed 25 to 30 m thick; a diorite fanglomerate exposed behind the lodge forms a vertical cliff 50 m high.

Fanglomerate near the Entiat fault was mapped by Whetten and Laravie (1976), and Whetten and Waitt (1978), and described by Laravie (1976). The coarsest rocks, having clasts more than 2 m in diameter, crop out adjacent to the fault (Figs. 3, 4) and were probably deposited as alluvial fans. Basinward, these rocks interfinger with fluvial sandstone, which, in turn, interfingers with lacustrine rocks of the Nahahum Canyon Member. Virtually all clast lithologies are known to occur in the Entiat Mountains. The fanglomerate is poorly exposed, but resistant clasts that weather out of the unit occur in soils and on the surface.

The core rocks of the Eagle Creek anticline formed a topographic high during deposition of the Nahahum Canyon Member; coarse conglomerates and sandstones occur adjacent to it. This suggests that the Chiwaukum graben may have developed one or more subsidiary graben during deposition of the Chumstick Formation.

Conglomerate and sandstone--Most of the Chumstick Formation consists of sandstone, pebbly sandstone, and conglomerate that form a thick, monotonous stratigraphic sequence (map units "Ts" and "Tcs"; Whetten and Laravie, 1976; Whetten and Waitt, 1978; Figs. 3, 4). Shale, mudstone, and coal-rich beds are much less abundant except in the Nahahum Canyon Member. Sandstone, the most common lithology, is typically white to buff-gray and occurs as thick massive beds that weather to bold, sparsely vegetated outcrops. Some sandstone beds grade upward from conglomerate or pebbly sandstone. Rocks of these lithologies are well exposed at the type section on the west limb of the Eagle Creek anticline from the confluence of Eagle and Chumstick Creeks to the core of the anticline. Other nearby areas of good outcrop are in Walker and Clark Canyons.

A fluvial origin for these rocks is indicated by imbricate clasts in conglomerate; graded, crossbedded, and channeled sandstone; rare ripple marks and flute casts; and organic remains such as leaves, branches, and logs. Paleocurrent directions determined from crossbedding show that stream flow from the area of the Entiat Mountains was generally to the southwest (Buza, 1977). Southwest-directed paleocurrent indicators found nearly to the Leavenworth fault suggest that during the time of deposition the Leavenworth fault had a much lower scarp than the Entiat fault. The gneissic core of the Eagle Creek anticline was a bedrock ridge that shed detritus both east and west within the graben.

Most clasts in conglomerates are of foliated metamorphic rocks, felsic volcanic rocks, and vein quartz; these rocks plus K-feldspar, intermediate plagioclase, and biotite are the most common clasts in the

sandstones. The proportion of constituents is variable; generally gneissic clasts are most common near the base of the unit, and most of the sandstones are feldspathic. The sandstones are extensively zeolitized, principally by laumontite, at some places by clinoptilolite.

The clast types are consistent with an Entiat source terrane. Some clasts of Chiwaukum Schist are found near the Leavenworth fault, which indicates that sediment was derived locally from the southwest side of the graben.

Tuff--Numerous tuff beds are interbedded with the pebbly sandstones in the lower part of the Chumstick Formation (Fig. 3). None were found in the Nahahum Canyon Member. Most are not mappable, but two are well exposed over large areas and are extremely useful as marker beds and mapping units. These tuffs have been given informal names, Eagle Creek tuff and Zeolite tuff (map units "Tt_1", and "Tt_3", respectively; Whetten and Laravie, 1976). The ages of zircons from these and other tuffs are given in Table 1.

The Eagle Creek tuff has been mapped for a distance of approximately 35 km on the west limb of the Eagle Creek anticline. It appears to be an ash-flow tuff. The average thickness is about 6 to 7 m; at one locality it is 12 m thick, and marked columnar jointing here suggests that the tuff may have been hot when deposited. The tuff is usually gray, relatively porous, and contains small bits of carbonized wood and sanidine phenocrysts. It is not well exposed, but its float is very distinctive and easily traced.

The Zeolite tuff (so named because it is extensively altered to clinoptilolite) is bedded and reworked and could more appropriately be called a tuffaceous sandstone. The alteration has produced a greenish cast on fresh surfaces. This unit averages about 10 m thick and has been mapped for a considerable distance.

The Zeolite tuff is well-exposed along the Eagle Creek road at the type section (SE¼, NW¼, Sec. 28, T25N, R18E; approximately 0.4 km east of Bjork Canyon). The Eagle Creek tuff is easily seen on the old Wenatchee highway east of Dryden (NW¼, NW¼, Sec. 36, T24N, R18E; approximately 0.8 km east of Olalla Canyon).

Lithology of the Nahahum Canyon Member

The Nahahum Canyon Member (map unit "Tsh"; Whetten and Laravie, 1976; Whetten and Waitt, 1978) is a shaly sandstone and shale (Figs. 3, 4). Bedding is commonly accentuated by thin laminae of biotite and organic matter. The rarity of sediment coarser than sand suggests lacustrine deposition in what may have been a large shallow lake or a number of smaller lakes. Some of the sand beds are turbidites. The Nahahum Canyon Member is poorly exposed, and landslides in Nahahum terrane are very common (Whetten and Waitt, 1978).

The contact with the lower part of the Chumstick Formation is conformable and has been mapped from the east limb of the Eagle Creek anticline westward toward the Leavenworth fault (Whetten and Laravie, 1976; J.T. Whetten, unpublished map). Southeast of Sec. 3, T25N, R18E, the contact is a normal fault that trends parallel to the axis.

The Nahahum Canyon Member grades laterally into sandstone and conglomerate of the Chumstick Formation near the Entiat fault and near the core of the Eagle Creek anticline. The occurrence of rocks of lacustrine, fluvial, and alluvial fan facies in belts that trend parallel to the fault suggests strong tectonic control of sedimentary facies during deposition (Whetten and Laravie, 1976; Whetten and Waitt, 1978). Reconnaissance mapping near the Leavenworth fault shows a similar pattern:

close to the fault, the Nahahum Canyon Member coarsens and interfingers with Chumstick conglomerate and sandstone.

The fine-grained rocks of the Nahahum Canyon Member occur in the type section on the east flank of the Eagle Creek anticline approximately 0.5 km east of the Van Creek road for approximately 1.3 km along the Eagle Creek road. A reference section that is particularly well exposed is designated on Easy Street approximately 2 km west of Sunnyslope (NE¼ Sec. 19, T23N, R20E). Here, sandstone turbidites are interbedded with lacustrine shales.

Thickness and Extent

The detail of geologic mapping in the Chiwaukum graben varies considerably, and accurate estimates of thickness and lateral extent of either the various components of the Chumstick Formation or of the formation as a whole are not available. With the exception of the Wenatchee Formation and younger surficial sediments and some possibly older rocks in the Wenatchee area (Gresens, 1976; 1977), all of the rocks in the graben belong to the Chumstick Formation. Because of structural complexities, the Nahahum Canyon Member is restricted to the northeast side of the graben and to the northwest end.

Whetten (1976) conservatively estimated 5,800 m of Chumstick Formation at the type section. Approximately the upper third (2,000 m) is Nahahum Canyon Member. These figures are not entirely reliable. Not only are the data uncertain, but the characteristics of the depositional environment, which include a basement of unknown relief, the probability of unequal subsidence, the possibility of subsidiary graben within the main graben, and rapid facies changes, suggest that sediment thickness may be extremely variable.

Age and Correlation

Ages of zircons from tuffs in the lower part of the Chumstick Formation, given in Table 1, average 44.6 m.y., which will be taken as the age of the lower part of the formation. No dates are available for the Nahahum Canyon Member, but the Wenatchee Formation, which overlies the Nahahum Canyon Member unconformably, is dated at approximately 34 m.y. (Table 1). Sedimentation was probably very rapid throughout Chumstick time.

Related igneous activity occurred in nearby areas at the time the Chumstick tuffs were deposited. A dacite dome located within the graben near Wenatchee (SE¼ Sec. 16, T22N, R20E) was dated by K-Ar at 43.2 ±.04 m.y. (R.W. Tabor, personal commun., 1978), and dacite from Old Gib Mountain at the north end of the graben and granodiorite from the Duncan Hill pluton in the Entiat Range have been dated at approximately 44 m.y. (Engels and others, 1976). Shallow intrusions and volcanic rocks associated with this igneous activity (such as the dikes now exposed in Corbaley Canyon 8 km east of Orondo on U.S. Highway 2) very likely provided the felsic volcanic and dike clasts that are abundant in the Chumstick Formation.

Several mafic-intermediate dikes were found to intrude sandstones and conglomerates of the Chumstick Formation. A dike in Walker Canyon (NE¼, SE¼ Sec. 20, T25N, R18E) was dated at 41.5 ±2.6 m.y. by the potassium-argon method on hornblende (R.W. Tabor, personal commun., 1976).

The Chumstick Formation may be approximately the same age as the Roslyn Formation, for which radiometric dates are not available. As noted, the Roslyn overlies the Teanaway Basalt, and R.W. Tabor (personal commun., 1977) reported a probable Teanaway Basalt flow interbedded with

the oldest part of the Chumstick Formation in the southwest part of the graben. Russell (1900, p. 119) noted the lithologic similarity between the Chumstick (Camas sandstone) and the Roslyn, although there is no evidence that the two units were connected.

WENATCHEE FORMATION (RLG)

The Wenatchee Formation is named for Wenatchee, Washington. The type and reference sections are in the foothills east and west of the city. The name has previously been used informally (V.E. Livingston, personal commun., 1974).

The type section is located on the northwest flank of Squilchuck Canyon at SE¼ Sec. 21, SW¼ Sec. 22, NW¼ Sec. 27, and NE¼ Sec. 28, T22N, R20E, where the formation is folded to form the Pitcher syncline (Patton and Cheney, 1971) (Fig. 5). Four reference sections are here designated: (1) the silica quarry in Dry Gulch at center Sec. 21, T22N, R20E; (2) Chopper Hill, located at the boundary between Secs. 7 and 8, T22N, R20E; (3) the west-facing bluffs overlooking the Columbia River in the NW¼ Sec. 23, T23N, R20E, from Blue Grade Road at the center of Sec. 23 to the north border of Sec. 23; and (4) the sandstone bluffs on the northwest side of Stemilt Canyon in SW¼ Sec. 25 and NW¼ Sec. 36, T22N, R20E. These will be referred to as the Dry Gulch, Chopper Hill, Blue Grade, and Stemilt Canyon reference sections (Fig. 6).

Type Section

At the type locality, the formation is divided into a lower sandstone and shale member and an upper conglomerate member. The lower sandstone and shale member is subdivided into (a) shale-dominated fluvial lower beds, (b) sandstone-dominated fluvial middle beds, and (c) shale

and sandstone upper beds of lacustrine origin. The subdivisions will be referred to as the lower shale, the middle sandstone, and the upper lake beds.

Sandstone and shale member--The base of the sandstone and shale member is not exposed, but structural relations indicate that it lies a few meters below the valley floor. The lower shale has an exposed thickness of about 145 m. It consists of thick beds of distinctive grayish-blue tuffaceous shale to siltstone, with thinner 0.5 to 3 m thick interbeds of buff, commonly limonitic, fine- to medium-grained, friable, crossbedded and channeled quartz sandstone. Muscovite flakes to 1 cm in diameter occur throughout the section in both shale and sandstone. Minor amounts of dark lithic fragments and/or carbonaceous fragments typically are present, but calcite, biotite, and feldspar are conspicuously absent. Intraformational grayish-blue siltstone clasts to 4 cm in diameter occur locally in sandstone, and thin layers of angular quartz conglomerate are present locally. At some places, thin coal lenses occur in shale. Red oxidized zones, presumably caused by subaerial weathering, occur in the upper part of the lower shale; partially oxidized rocks demonstrate a transition to grayish-blue shale. A prominent oxidized zone, about 1 m thick, marks the top of the lower shale.

The middle sandstone, about 70 meters thick, is mostly composed of 5- to 15-m-thick beds of crossbedded medium- to coarse-grained sandstone with thinner interbeds of grayish-blue shale and siltstone similar to beds in the lower shale unit. Conglomeratic interbeds with quartz clasts to 2.5 cm in diameter are common within sandstone beds. Quartz grains

are angular to subangular, and the rock is poorly sorted, friable, and porous. Lithic fragments and muscovite flakes typically are present in small amounts (<1%).

The upper lake beds are about 25 m thick. They consist of poorly exposed brown fissile shale that grades upward into siltstone and sandstone. In contrast to the grayish-blue lower shale, the brown shale of the lake beds lacks mesoscopic muscovite flakes. Siltstone and sandstone are light gray to almost white, but weather to light yellowish brown. Sandstone ranges from fine to medium grained and is lithologically similar to sandstones of the lower shale and middle sandstone except that muscovite is not common. It is better sorted and better cemented than the friable sandstone of the lower units; locally it is calcite cemented. Siltstone and sandstone typically are thinly and evenly laminated and locally crossbedded; laminations are commonly accentuated by thin (<1 mm) layers rich in organic material. Leaf fossils are common throughout the unit. Dark-reddish-brown iron oxide concretions and irregular banding are common.

Conglomerate member--About 15 meters of the conglomerate member crops out at the type section. The upper contact is not exposed, and the uppermost part of the member is covered by basalt slide rock. The contact with the upper lake beds is sharp and appears slightly discordant (estimated as $\leq 5°$), particularly when viewed from a distance.

The member contains both conglomerate and sandstone. The conglomerate is very poorly sorted with rounded to subrounded clasts ranging to 20 cm in longest dimension. Clasts are mainly felsic volcanic rocks.

Varieties of rhyolite (porphyritic, fine-grained nonporphyritic, and flow-banded) are the most common, but composition ranges to dacite. Altered volcanic rocks and irregular masses of white pumice occur locally. The second most common clast lithology is white vein quartz. Dark fine-grained clasts of silicified volcanic rock are present in minor amount. Conglomerate is common, and clast size is larger at the bottom of the unit, but conglomerate may occur anywhere within the member. The sandstone, which includes the matrix of the conglomerate, consists of coarse-grained poorly sorted quartz and dark cherty lithic fragments in a matrix of powdery white clay. The sandstone is very friable and appears to have been a feldspathic sandstone in which the feldspar has altered to clay. Where it crops out, the conglomerate member is strikingly white, the color of dry bone, owing to the clay matrix. Limonitic to hematitic bands and concretions occur within the unit.

Geomorphic expression--The lower shale forms subdued, featureless slopes. The middle sandstone forms prominent, but irregular, sandstone bluffs. The sandstone part of the upper lake beds is a distinctive cliff-former. The conglomerate member forms white cliffs.

Reference Sections

The reference sections are designated to point up lateral variability within the Wenatchee Formation and to demonstrate the relation of the Wenatchee Formation to older rocks.

Dry Gulch reference section--The Dry Gulch reference section, less than 1 km northwest of the type section, demonstrates that the lithologic subdivision of the shale and sandstone member at the type section does not persist over long distances. The uppermost red oxidized zone is

presumed to correlate with the prominent red zone that separates lower shale from middle sandstone at the type section, and the thickness of sediment below this marker horizon is approximately the same at both the type and reference sections. Rather than being dominated by shale, however, the lower beds at the Dry Gulch reference section are composed almost entirely of medium- to coarse-grained, friable quartz sandstone. Between the marker horizon and the base of the upper lake beds is a section dominated by sandstone lithologically similar to the middle sandstone of the type section, but only about 17 m thick (compared with 70 m at the type section).

On the northwest slope of Dry Gulch, across the valley from the quarry, the entire section between the base of the formation to the upper lake beds is dominated by shale, whereas the equivalent section at the quarry is dominated by sandstone. Clearly the sandstone beds of the fluvial unit have the geometry of large lenses that do not correlate over even relatively short distances. A prospect cut at the eastern mouth of Dry Gulch exposes a sand lens that ranges from zero to 4 m thick over a horizontal distance of 30 m, thickening southward in the direction of the quarry.

A white porcelain-like fine-grained tuff cropping out in the lower quarry face in a cut that has since been destroyed by further mining provided a fission-track age of 33.4 ±1.4 m.y. (sample DF-1112, Table 1).

Blue Grade reference section--The Blue Grade reference section best exposes the unconformity between the Wenatchee Formation and the crystalline basement rocks (Swakane Biotite Gneiss), described by Glover (1941)

as the contact between metamorphic rocks and basal beds of the Swauk Formation. The Swakane is metasedimentary plagioclase-quartz-biotite schist and gneiss weathered to a depth of at least 15 to 20 m, producing a paleosol below the unconformity.

The reference section is mostly of fluvial origin, in lithology identical to rocks of the type section except that angular feldspar grains to 6 mm long occur in sandstones near the base. Thin beds of white tuff are common; one of these tuffs was dated at 34.5 ±1.2 m.y. (sample DF-948, Table 1).

Beds of brown shale, 0.5- to 1-m-thick, containing abundant leaf fossils can be seen on the north side of Blue Grade Road some 120 m east of a small quarry at the center of Sec. 23, T23N, R20E. Similar, but thicker (3 m) beds occur in a side canyon 400 m south. These beds resemble, and possibly correlate with, the shaly part of the upper lake beds of the type section but, in contrast, are overlain by additional fluvial sandstone and shale.

Chopper Hill reference section--The Chopper Hill reference section displays the angular unconformity between the Wenatchee Formation and a unit that is probably Swauk Formation (Gresens, 1976, 1977). Generally flat-lying Wenatchee Formation overlies vertical to near-vertical beds of arkose and shale. A 12- to 15-m-thick weathering profile is present in the underlying unit; it ranges from arkose with numerous limonite-stained fractures to a powdery white paleosol.

A 6-m-thick slightly feldspathic sandstone (which locally contains clasts of underlying Swauk(?) at its base) lies at the bottom of the

section. Sandstones interbedded with grayish-blue tuffaceous shale and siltstone become thinner and less frequent upward, and the section correlates with the lower shale of the type section. It contains a few sills of reddish-brown andesite related to a nearby intrusion.

Stemilt Canyon reference section--An angular unconformity between the Wenatchee Formation and the Chumstick Formation is well exposed at the Stemilt Canyon reference section. Nearly flat-lying Wenatchee overlies Chumstick that dips as much as 45°. In contrast to the Blue Grade and Chopper Hill reference sections, there is no deeply weathered zone in the underlying formation. This unconformity and the unconformity between Wenatchee Formation and overlying Yakima Basalt were noted earlier by Chappell (1936) and Patton and Cheney (1971).

At Stemilt Canyon, the base of the Wenatchee Formation is a thick basal sandstone ($\geq$30 m thick), whereas at the type section and other localities, basal sandstone is either thin or absent. Lithologically, the basal sandstone is typical fluvial quartz sandstone of the type section.

Distinguishing Characteristics

Lithology best serves to distinguish Wenatchee Formation from Chumstick and Swauk Formations. The nearly pure quartz sandstone, generally lacking feldspar, biotite, and calcite, contrasts strongly with the biotite-rich, commonly calcite-bearing, feldspathic sandstones of the older units. Chumstick sandstone is locally quartzose and may resemble Wenatchee sandstone, but it usually contains minor biotite. Sedimentary structures are similar in all formations and are of little use in distinguishing them.

The combination of grayish-blue shale, buff sandstone, red oxidized zones, and lighter colored tuff beds gives rise to a variegated aspect that is distinctive when viewed from a distance. Younger (possibly Miocene) beds near the town of Malaga that contain variegated shales can be distinguished from Wenatchee Formation partly because they apparently are primary redbeds (they do not show transitions to unoxidized parent rocks), whereas red color in the Wenatchee Formation is produced by oxidation of grayish-blue shale and siltstone.

Conglomerates with similar clasts of silicic volcanic rocks occur in both the Chumstick Formation and the upper conglomerate member of the Wenatchee Formation. Conglomerate of the Wenatchee is sufficiently distinctive that anyone who has seen it at the type locality is not likely to confuse it with older conglomerates.

Contacts, Boundaries, and Extent of the Formation

The Blue Grade, Chopper Hill, and Stemilt Canyon reference sections clearly demonstrate that the Wenatchee Formation is unconformable on all older units, ranging from Precambrian(?) Swakane Biotite Gneiss (Mattinson, 1972) to late Eocene Chumstick Formation. The Wenatchee Formation is overlain unconformably by Miocene Yakima Basalt at the type section and the Dry Gulch and Stemilt Canyon reference sections (Chappell, 1936; Patton and Cheney, 1971). (R.W. Tabor (personal commun., 1977) and his coworkers disagree, considering the overlying basalt to be remnants of large landslides of possible Pliocene age, rather than Yakima Basalt in place). There is evidence that an unnamed formation, possibly of Miocene age, underlies Yakima Basalt near Malaga. Presumably, it is unconformable on Wenatchee Formation, but an exposure of the contact is not known.

The Wenatchee Formation crops out on the eastern foothills of the Cascade Range. To the east, presumably a much greater extent of Wenatchee Formation is present below the Columbia Plateau, underlying the Miocene basalt flows. To the west in the Cascade Range, the absence of Wenatchee Formation must be due at least in part to erosion. A few erosional remnants of Wenatchee Formation occur in the Entiat Range; a particularly good example is along Burch Mountain Road in center Sec. 32, T24N, R20E. The formation is in fault contact with Chumstick Formation west of the type section, and no other outcrops of Wenatchee have been noted west of this major fault. The fault is well exposed (1) in a roadcut on the west side of Squilchuck Creek Road, 0.4 km north of the junction with the Wenatchee Heights Road and (2) on Halvorson Loop Road, both in the NW¼ Sec. 4, T21N, R20E (Fig. 6). The fault is high-angle, striking northwest, and the Wenatchee Formation is nearly vertical northeast of the fault trace.

Presumably the Wenatchee Formation once had a much greater areal extent. The true thickness is not known, but the maximum observed thickness is about 300 m.

Environment of Deposition and Probable Source of Sediment

The lower member of the Wenatchee Formation was probably deposited on a surface of low relief. Buried weathering profiles on all underlying units have been noted at the reference sections and elsewhere. Streams flowing across the surface account for the lenslike form of the fluvial sandstones. The grayish-blue shales and siltstones may be flood-plain deposits, and subaerial exposure probably produced the red oxidation. Local ponding would explain the interbedded lacustrine sediments.

The tuffaceous component of shale and siltstone presumably resulted from widespread erosion and reworking of volcanic ash similar to the components of the preserved tuff beds. The fine grain size and thinness of white tuff beds suggest that the ash drifted over from a distant site of silicic volcanism. Mixing of ash with fine detrital sediment is indicated by muscovite flakes that are common in tuffaceous shale and siltstone but not present in pure ash layers. The larger muscovite flakes are pegmatitic and suggest a crystalline source terrane.

Basal conglomerate is present locally in the Wenatchee Formation; the clasts are composed of rocks derived from underlying formations: arkosic clasts from Swauk(?) Formation, clasts of felsic volcanic rocks from Chumstick Formation, and angular clasts of vein quartz from Swakane Biotite Gneiss. An argument can be made for local derivation of the material composing basal sandstones in which a basal conglomerate occurs. For sandstone higher in the section, a more distant source could be argued. But a characteristic of all Wenatchee sandstone is the high angularity of quartz grains, suggesting a nearby source. Buza (1977) determined that the sediment transport direction in the Wenatchee Formation is generally east to west. It is suggested that subdued relict topographic highs of crystalline basement rock protruded above the surface of low relief east of the Entiat fault. A high ratio of chemical-to-mechanical weathering rates caused deep weathering that destroyed mafic minerals and feldspar and left a residue of clay, quartz, and muscovite; much of the residual quartz was derived from vein quartz that is common in the Swakane Biotite Gneiss. Episodes of flooding could have been particularly effective in removing residual sediment from highlands and sorting it to produce the clean angular quartz sand of the Wenatchee Formation.

The upper conglomerate member of the Wenatchee Formation represents a sharp change from the lower member in terms of environment of deposition and sediment source. Tectonic uplift or nearby volcanism is necessary to bring about a change from a surface of low relief to conditions that could supply the coarse volcanic detritus of the upper member. The areal extent of the upper member is very limited, and nothing is known about sediment transport direction or possible source rocks. Volcanic clasts could be (1) material reworked from Chumstick Formation, (2) clasts from the same source terrane that provided volcanic clasts to the Chumstick and had been reexposed, or (3) clasts from an entirely different, unknown source.

Age and Correlation

Two fission-track dates from volcanic interbeds in the sandstone and shale member of the Wenatchee Formation are 33.4 ±1.4 m.y. and 34.5 ±1.2 m.y. (Table 1), or early Oligocene. Possibly the formation correlates with the Big Basin Member of the John Day Formation of eastern Oregon (Fisher and Rensberger, 1972), which crops out below Columbia River Basalt 270 km to the south. Dates from this lower member of the John Day Formation are 31.1 to 31.5 m.y. (Evernden et al., 1964) and 36.4 ±1.1 m.y. (Swanson and Robinson, 1968).

The upper conglomerate member of the Wenatchee Formation was included as part of the formation because (1) there is only slight discordance between the members, and together they form a convenient mappable unit; (2) the members are folded together at the type locality, where the structure (Pitcher syncline) is eroded and overlain unconformably by Yakima Basalt or basaltic landslide deposits. As noted, sedimentary beds

of possible Miocene age occur below Yakima Basalt near Malaga. Possibly the upper conglomerate member correlates with the younger beds, but definitive evidence is not available at this time. If the age of the upper conglomerate member is shown to be significantly younger than 34 m.y., then this unit should be discarded as a member of the Wenatchee Formation.

FISSION-TRACK DATING (CWN)

Fourteen fission-track ages were determined on minerals from 12 samples of the Chumstick and Wenatchee Formations (Table 1). Twelve of the ages were determined on zircon, two on apatite. The zircons were dated by the external detector method (Naeser, 1969) on fossil tracks etched with KOH-NaOH eutectic melt developed by Gleadow et al. (1976), the apatite using the population method (Naeser, 1967) on fission tracks etched with 7% HNO_3.

The zircons from the tuffs in the Chumstick Formation were especially difficult to date because of a larger component of detrital zircons in the concentrate, which had ages ranging between 50 and 90 m.y. In some determinations, it was not possible to count the five or six crystals necessary for a small standard deviation.

The average ages of the tuffs in the Chumstick are statistically the same and cannot be separated. This similarity suggests very rapid sedimentation. The one apatite dated from the Chumstick (76-67) is discordant, having an apparent fission-track age of 15 m.y., whereas age for the coexisting zircon is 44.4 m.y. Apatite is very susceptible to fission-track annealing (Naeser and Faul, 1969); a temperature of 90-100°C, if maintained for 10^6 or more years, is sufficient to drastically reduce the

fission-track density in apatite. This discordance indicates that this part of the Chiwaukum graben was heated to a temperature >80°C and <175°C (lower annealing of zircon). The rocks cooled in middle Miocene time, probably because of uplift.

The apatite and zircon from the Wenatchee Formation (27a) are concordant, which precludes there having been any significant burial and uplift. Sample MS-4C has an anomalously old age: all of the zircons in this tuff(?) are detrital.

CONCLUSIONS

The Chiwaukum graben is a key area for understanding the sequence of depositional, erosional, and tectonic events during Eocene and Oligocene time in central Washington. We have provided a stratigraphic framework for the interpretation of the geologic history of the region by recognizing two unconformity-bounded nonmarine formations within the graben: the Chumstick Formation (approximately 45 m.y. old), and the Wenatchee Formation (approximately 34 m.y. old). These units are younger than the Swauk Formation, which appears to be restricted mostly to areas west of the graben.

The stratigraphy of the Chumstick and Wenatchee Formations indicates that the graben formed during the time of deposition and that the sediments were derived locally from sources near the margins. There is no evidence for strike-slip movement along the border faults during Tertiary time. At least one subsidiary graben formed within the main graben. The scarp made by the Entiat fault appears to have been considerably higher than the scarp made by the Leavenworth fault during deposition of the Chumstick Formation; sediment was transported to the southwest across the

graben. Relief in the source area was very subdued during deposition of the Wenatchee Formation. Both units were deposited primarily by rivers and streams and in lakes.

Table 1. Fission-track age data for Wenatchee and Chumstick Formations.

The constants used to calculate fission track ages correspond with the constants in use for K-Ar dating (Steiger and Jager, 1977). This results in an increase in the fission track age of about 3% over previously used constants.

Sample	Subunit	Mineral	Ps $\times 10^6$ τ/cm^2	Pi $\times 10^6$ τcm^2	ϕ $\times 10^{15}$ n/cm^2	T $\times 10^6$ yr	$\pm 2\sigma$ $\times 10^6$ yr	U ppm	Numbe grai coun
			WENATCHEE FORMATION						
LS-6C (DF-1112)	Tuff near base of Wenatchee Form.	Zircon	7.08 (1180)	13.18 (1095)	1.04	33.4	1.4	400	6
MS-4C (DF-1113)	Same locality as LS-6C; but strati-graphically higher	Zircon	5.11 (1491)	6.51 (950)	1.05	49.1	2.3	200	8
#27a (DF-948)	Tuff near base of Wenatchee Form.	Zircon	2.28 (666)	6.05 (882)	1.53	34.5	1.2	130	5
#27a (DF-949)	Tuff near base of Wenatchee Form.	Apatite	0.0523 (109)	0.1138 (237)	1.45	39.8	9.0	2.5	50
			CHUMSTICK FORMATION						
75-211 (DF-956)	Zeolite tuff	Zircon	3.34 (278)	6.98 (291)	1.47	41.9	6.8	150	3
75-209 (DF-954)	Zeolite tuff	Zircon	4.85 (516)	10.91 (537)	1.49	42.7	5.1	220	3
75-202 (DF-953)	Zeolite tuff	Zircon	5.98 (360)	10.97 (330)	1.50	48.8	7.2	240	2
75-215 (DF-955)	Tuff "Tt_2"[1]	Zircon	5.80 (886)	12.00 (917)	1.48	42.7	3.7	260	2
75-191 (DF-951)	Tuff "Tt_2"[1]	Zircon	5.17 (766)	10.11 (749)	1.52	46.4	1.9	210	5
75-200 (DF-952)	Eagle Creek tuff	Zircon	8.65 (881)	18.26 (930)	1.51	42.7	1.5	390	5
75-124C (DF-950)	Eagle Creek tuff	Zircon	11.6 (1315)	16.2 (936)	1.10	46.1	1.9	470	5
75-x	Eagle Creek tuff	Zircon	(855)	(805)	1.46	46.2	1.8		4
76-67 (DF-1495)	Tuff "Tt"[2]	Apatite	0.368 (1532)	1.255 (2614)	0.86	15.1	3.0	42	50
76-67 (DF-1494)	Tuff "Tt"[2]	Zircon	6.28 (669)	9.37 (499)	1.11	44.4	2.6	240	7

$\lambda_F = 7.03 \times 10^{-17}\ yr^{-1}$

( ) = number of tracks counted

[1]Whetten and Laravie (1976)

[2]Whetten and Waitt (1978)

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Figure 1. Generalized geology of central Washington and locations of figures 3 and 6. Geology east of the Columbia River is not shown. The distribution of Wenatchee Formation, which occurs in small patches not appropriate to the scale of this map, is shown on figure 6. "Ti" refers to a large intrusion of hornblende andesite.

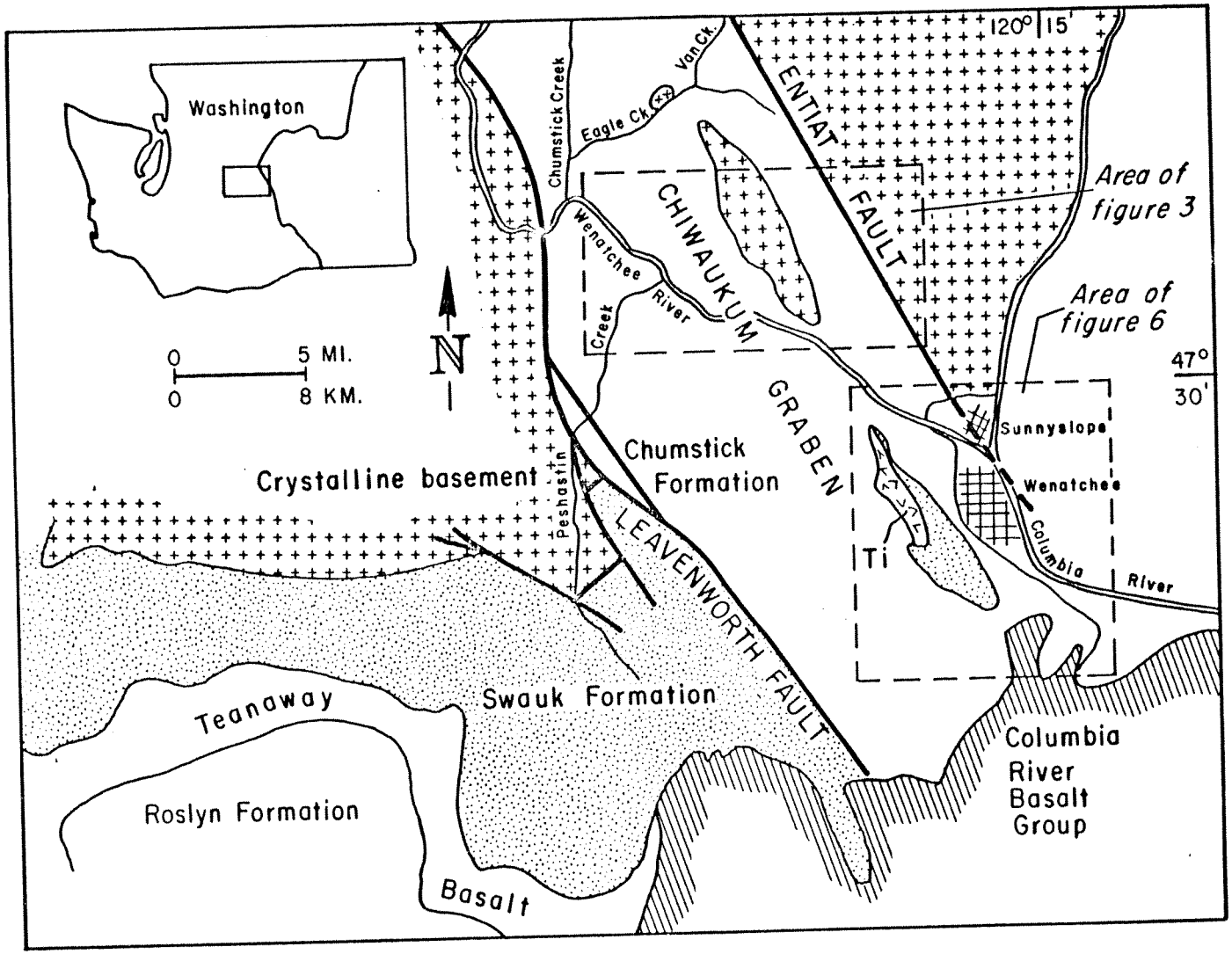

Washington
0 5 MI.
0 8 KM.
N
Chumstick Creek
Eagle Ck.
Van Ck.
Wenatchee River
Creek
Peshastin
CHIWAUKUM GRABEN
ENTIAT FAULT
120° 15'
Area of figure 3
Area of figure 6
47° 30'
Sunnyslope
Wenatchee
Columbia River
Ti
Chumstick Formation
Crystalline basement
LEAVENWORTH FAULT
Swauk Formation
Teanaway
Roslyn Formation
Basalt
Columbia River Basalt Group

Figure 2. Stratigraphic column showing rock units discussed in this report.

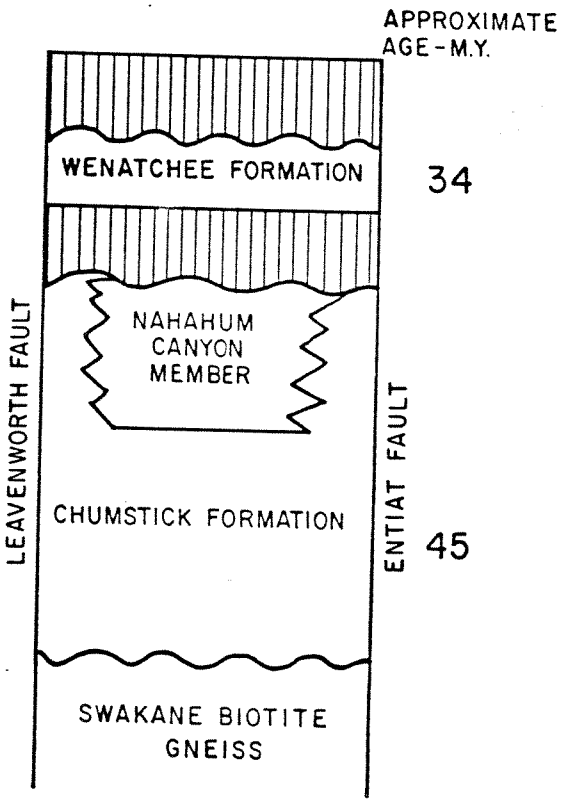

APPROXIMATE
AGE-M.Y.
WENATCHEE FORMATION
34
NAHAHUM
CANYON
MEMBER
LEAVENWORTH FAULT
ENTIAT FAULT
CHUMSTICK FORMATION
45
SWAKANE BIOTITE
GNEISS

Figure 3. Geologic sketch map showing bedrock lithologies of the Chumstick Formation in the central part of the Chiwaukum graben.

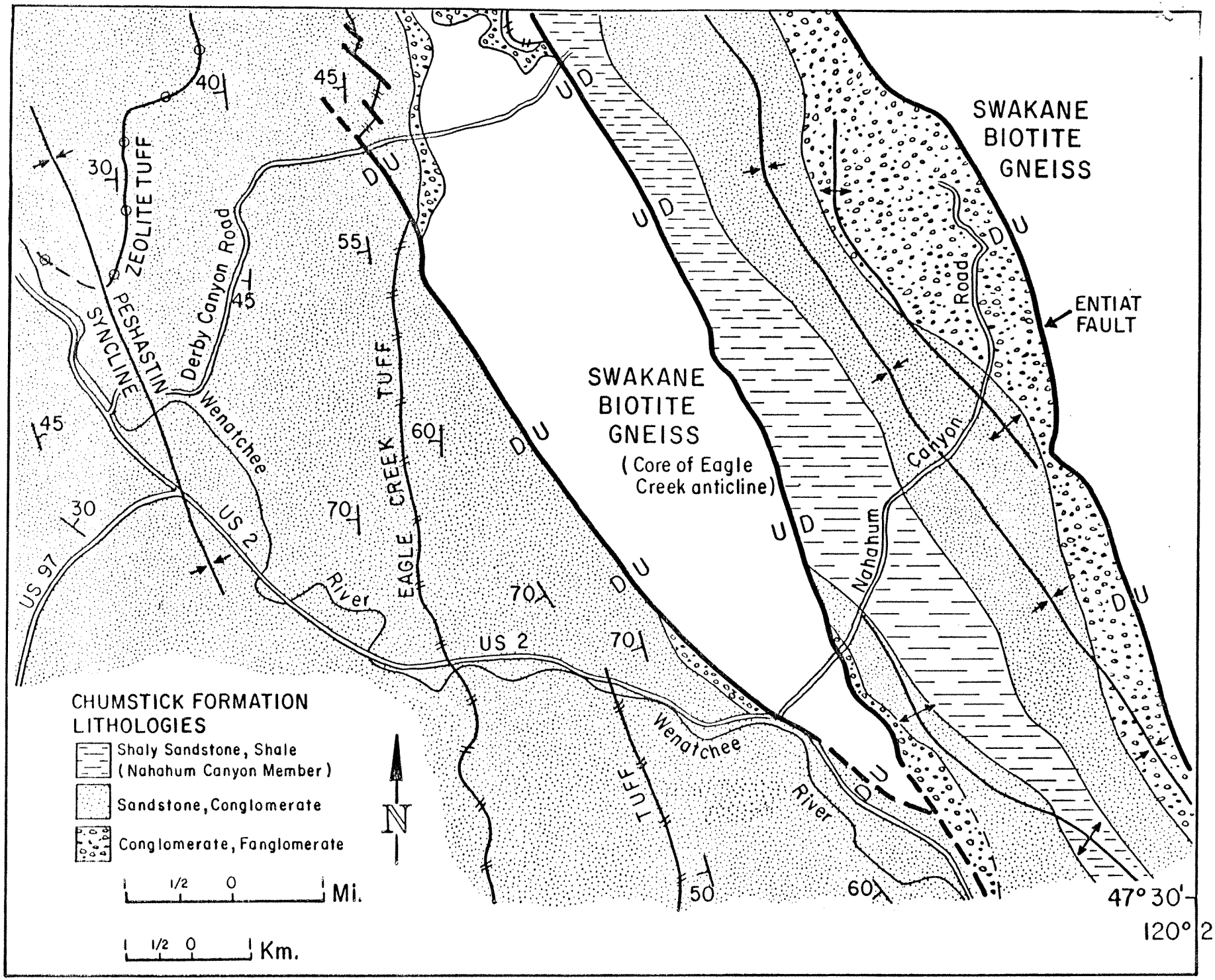

SWAKANE BIOTITE GNEISS
SWAKANE BIOTITE GNEISS
(Core of Eagle Creek anticline)
ENTIAT FAULT
ZEOLITE TUFF
PESHASTIN SYNCLINE
Derby Canyon Road
Wenatchee
River
EAGLE CREEK TUFF
US 2
US 97
Nahahum Canyon Road
TUFF
CHUMSTICK FORMATION LITHOLOGIES
Shaly Sandstone, Shale (Nahahum Canyon Member)
Sandstone, Conglomerate
Conglomerate, Fanglomerate
N
1/2 0 Mi.
1/2 0 Km.
47° 30'
120° 22'3

Figure 4. Generalized cross section through the northern part of the Chiwaukum graben prior to folding. Not drawn to scale.

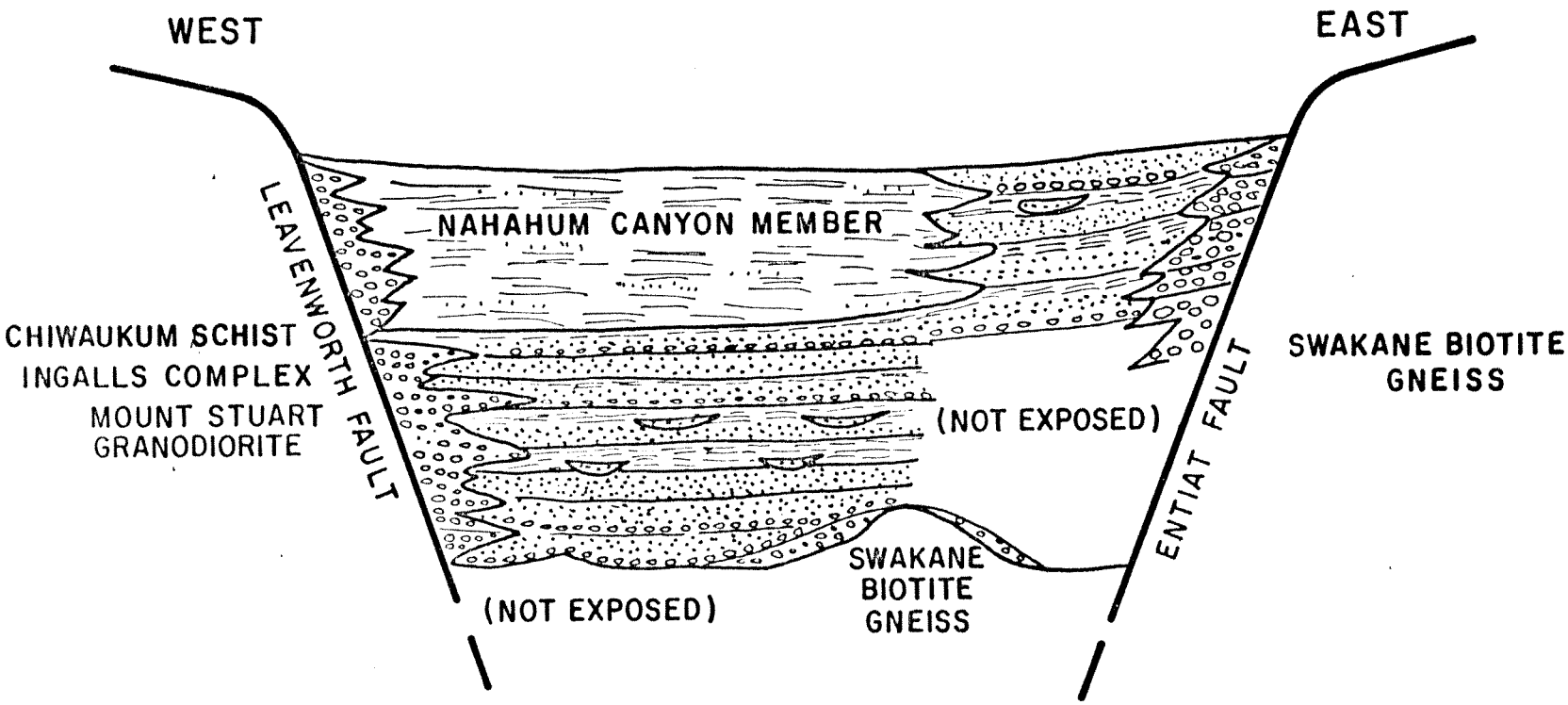

WEST
EAST
NAHAHUM CANYON MEMBER
LEAVENWORTH FAULT
CHIWAUKUM SCHIST
INGALLS COMPLEX
MOUNT STUART
GRANODIORITE
(NOT EXPOSED)
ENTIAT FAULT
SWAKANE BIOTITE
GNEISS
(NOT EXPOSED)
SWAKANE
BIOTITE
GNEISS

Figure 5. The type section of the Wenatchee Formation in the Pitcher syncline. View is to the northwest showing the exposures on the north side of Squilchuck Canyon. Symbols used: YB, Yakima Basalt; Cg, conglomerate member of Wenatchee Formation; UL, upper lake beds; MS, middle sandstone unit; LS, lower shale unit (UL, MS, and LS comprise the sandstone and shale member of the Wenatchee Formation); Ch, Chumstick Formation; S(?), probable Swauk Formation; SZ, silicified zone (mostly silicified sediment); IF, inferred thrust fault. YB is capping the mesa above the Pitcher Syncline.

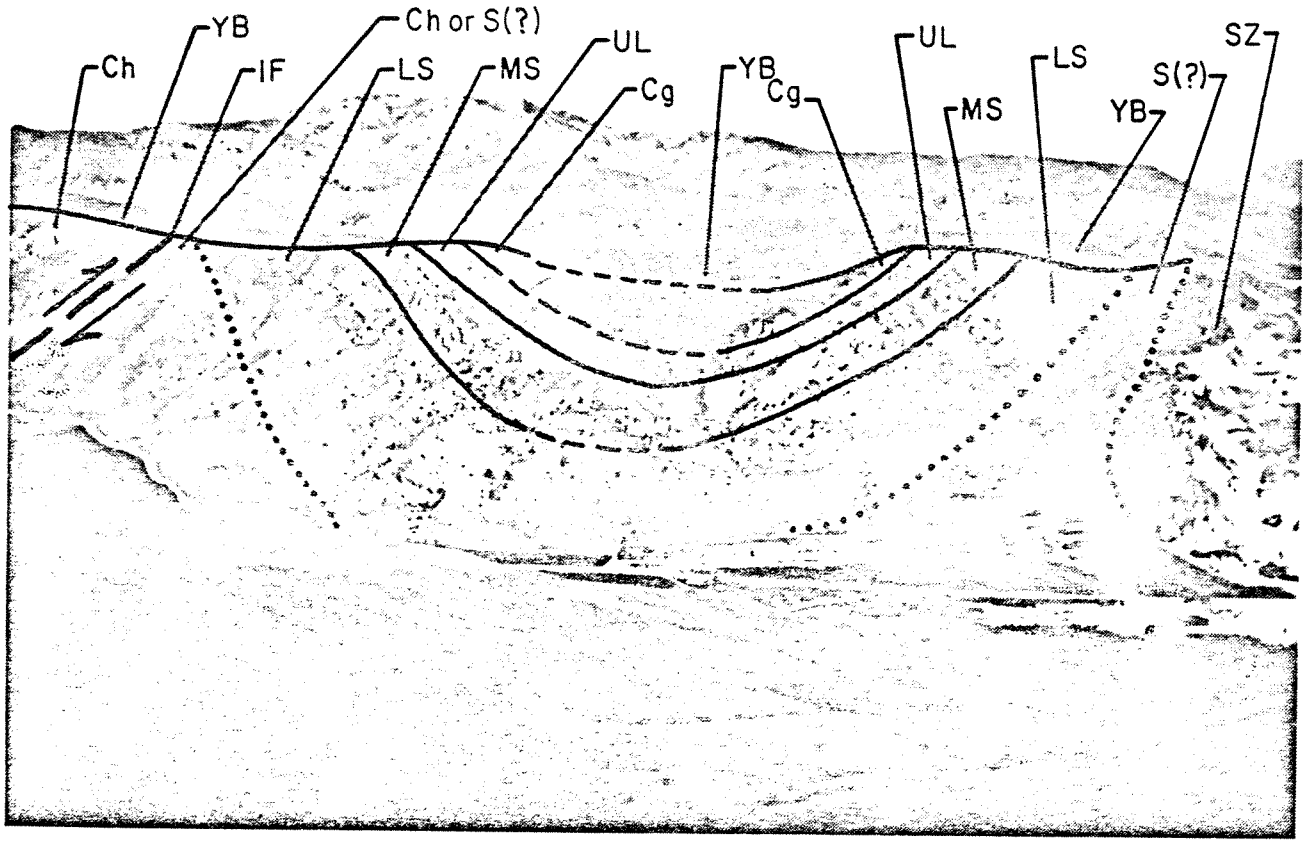
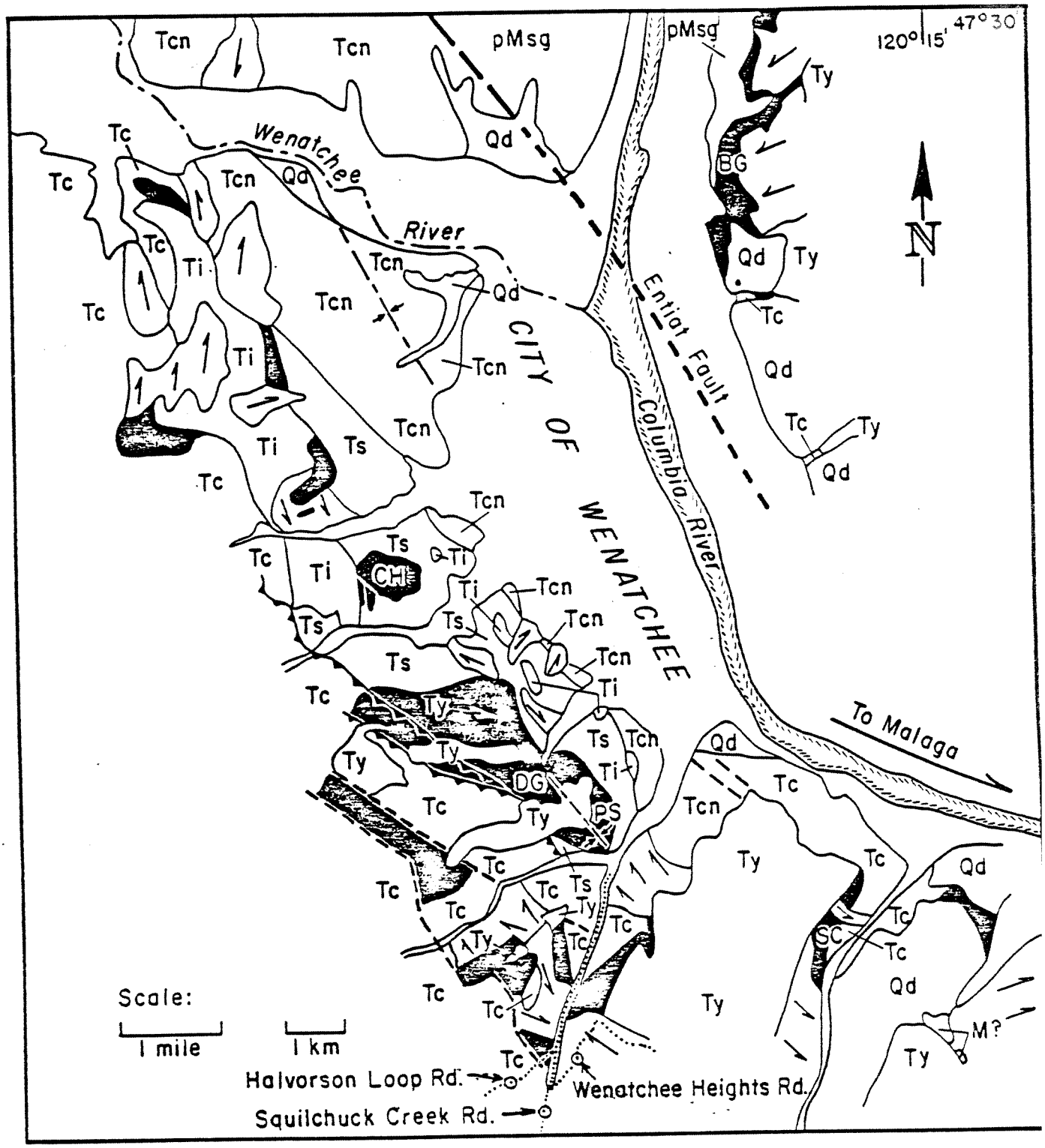

Ch
YB
IF
Ch or S(?)
LS
MS
UL
Cg
YB
Cg
UL
MS
LS
YB
S(?)
SZ

Figure 6. Distribution of Wenatchee Formation around the city of Wenatchee, Washington, and locations of type and reference sections. Outcrop areas of the Wenatchee Formation are shown entirely in black. Symbols for other geologic formations: pMsg, pre-Mesozoic Swakane Biotite Gneiss; Ts, probable Swauk Formation; Tc, Chumstick Formation; Tcn, Nahahum Canyon facies of the Chumstick Formation; Ty, Yakima Basalt; M?, sedimentary rocks of possible Miocene age; Ti, Tertiary intrusive rocks (andesite to rhyolite); Qd, various deposits of Quaternary age such as lake beds, terrace deposits, loess; arrows, Quaternary to Recent landslides; unlabeled blank areas in main part of map, Quaternary to Recent alluvium. Faults are shown as dashed lines, except for thrust faults which are shown as barbed lines. Code for type and reference sections: PS, Pitcher syncline; CH, Chopper Hill; DG, Dry Gulch; SC, Stemilt Canyon; BG, Blue Grade. A more detailed map, with structural data, is published in a field guide (Gresens, 1977


120°15'
47°30'
N
Wenatchee
River
CITY OF WENATCHEE
Entiat Fault
Columbia River
To Malaga
Tcn
pMsg
Qd
Tc
Ti
Ts
Ty
BG
CH
DG
PS
SC
M?
Scale:
1 mile
1 km
Halvorson Loop Rd.
Squilchuck Creek Rd.
Wenatchee Heights Rd.